

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B60S 1/08	A1	(11) International Publication Number: WO 99/14088 (43) International Publication Date: 25 March 1999 (25.03.99)
(21) International Application Number: PCT/US98/18899		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
(22) International Filing Date: 10 September 1998 (10.09.98)		
(30) Priority Data: 08/931,118 16 September 1997 (16.09.97) US		
(71) Applicant: GENTEX CORPORATION [US/US]; 600 North Centennial, Zeeland, MI 49464 (US).		
(72) Inventors: STAM, Joseph, S.; 345 South Lakeshore Drive, Holland, MI 49424 (US). BECHTEL, Jon, H.; 136 Sunrise Drive, Holland, MI 49423 (US). ROBERTS, John, K.; 1061 Plymouth Avenue, S.E., East Grand Rapids, MI 49506 (US).		Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>
(74) Agents: CHUEY, Mark, D. et al.; Brooks & Kushman, 2nd floor, 1000 Town Center, Southfield, MI 48075 (US).		
(54) Title: MOISTURE SENSOR AND WINDSHIELD FOG DETECTOR		
<p>The diagram illustrates a cross-sectional view of a moisture sensor assembly. At the top, a rectangular housing contains a lens element (68) and a sensor module (66). A cable (34) extends from the side of the housing. Below the housing, a larger rectangular component (32) is shown, which appears to be a sensor array or lens housing. A smaller component (33) is attached to the bottom edge of the main housing. Labels 30 and 36 point to specific features on the lower part of the housing.</p>		
(57) Abstract		
<p>A control system (20) for automatically detecting moisture on the windshield (26) of a vehicle. The automatic moisture detecting system (20) includes an optical system (30) for imaging a portion of the windshield (26) onto an image array sensor (32), such as a CMOS active pixel sensor. The voltages of each of the pixels which represents the illumination level is converted to a corresponding gray scale value by an analog digital converter (35). The gray scale values corresponding to the image are stored in memory (38). The spatial frequency composition of the gray scale values are analyzed to determine the amount of rain present. In order to provide a control signal to control the operation of the windshield wipers (40) of the vehicle as a function of the amount of moisture present. The system is also adapted to detect the level of fog both on the interior of the windshield (26) as well as the exterior of the windshield (26). By providing a system for automatically detecting the presence of fog on the interior and exterior of the windshield (26), serious performance limitations of known automatic rain sensors are eliminated.</p>		

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakhstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

-1-

MOISTURE SENSOR AND WINDSHIELD FOG DETECTOR

Technical Field

The present invention relates to a system for automatically detecting the presence of moisture on a surface such as the surface of a windshield of a vehicle for an automobile, in order to automatically actuate the vehicle's windshield wipers and/or defroster or defogging system.

Description of the Prior Art

In conventional windshield wiper systems, the windshield wipers are actuated based upon the elapsed time between wipes rather than the moisture level on the exterior of the windshield. During conditions of relatively consistent rainfall, for example, the time interval can be adjusted to correspond to the amount of time in which the rain accumulates to the point of the desired visibility level. Unfortunately the rate of rainfall may vary dramatically over a given period of time. Additionally, traffic conditions may also cause varying amounts of rain to fall on the windshields due to traffic conditions, such as a passing truck or the like. As a result, during such conditions, the wiper time interval must frequently be adjusted which can be cumbersome.

Various systems are known which automatically control the interval between wipes of the windshield wipers based upon moisture on the vehicle windshield. In some known systems, various coatings are applied to the vehicle windshield. Electrical measurement of those coatings are used to provide an indication of the moisture content on the windshield. Unfortunately such methods require relatively expensive processes which makes such system commercially non-viable. Other systems for automatically sensing the moisture content on a vehicle

-2-

windshield are also known. For example, optical systems are known which measure the difference of reflected light of a dry windshield versus a wet windshield. Unfortunately, the optical method is susceptible to interference from external light sources and thus provides inadequate performance. Other known
5 systems must be adhered to the windshield which complicates the windshield replacement. As a result of such complications, moisture sensors are rarely found on vehicles.

Another system for automatically detecting the moisture content on a windshield is disclosed in Japanese Laid Open Patent Application No.
10 Hei>(1995)-286130 which describes the use of a charge coupled device (CCD) image sensor to image a portion of the vehicle windshield in order to detect raindrops. The system described therein computes the sum of the differences between each pixel and the average of all pixels. Unfortunately headlamps of oncoming vehicles will create a bright spot in the image which would be difficult
15 to completely blur and likely be interpreted as rain. Moreover, in order for such a system to work effectively, images from the distant scene must be completely blurred. Otherwise, there will be dark and light regions in the distant scene. Although there is no optical system disclosed in the Japanese laid open Patent Application for accomplishing this objective, it would be very difficult to develop
20 an optical system to completely blur an oncoming headlamp. Failure to blur oncoming headlamps could cause false triggering of the system disclosed in the above-identified Japanese laid open Patent Application.

Another problem with automatic rain detection systems is the inability of the system to detect the operation of the windshield wipers. In certain
25 cold climate conditions, the windshield wipers are known to freeze to the windshield. In such a situation, since the moisture is not being removed by the wipers, an automatic rain sensing device would continuously command the wipers to actuate, even though the wipes are frozen to the windshield, potentially damaging the windshield wiper system.

-3-

Another known problem with known systems is the inability to detect fog on the interior and exterior of the windshields. As mentioned above, automatic moisture detection systems, such as disclosed in the above-identified laid open Japanese Patent Application, are based upon the ability to detect raindrops on the windshield. When a uniform fog or mist covers the vehicle windshield, systems, such as the system disclosed in the Laid Open Japanese Patent Application, are unable to sense such moisture on the exterior of the windshield. As a result, during such a condition, the windshield wipers will have to be manually actuated, thereby partially defeating the purpose of an automatic rain sensor and windshield wiper control system making the feature a lot less desirable.

In other situations, fog develops on the inside of the windshield independent of the moisture content on the exterior of the windshield. In such a condition automatic rain sensing systems, such as disclosed in the Laid Open Japanese Patent Application, are unable to detect the moisture content on the exterior of the vehicle windshield until after the fog on the interior of the windshield is cleared. In such a condition, a defroster or defogger system would have to be manually actuated to remove the interior fog on the windshield. The automatic rain sensor would not be operable during such a condition until the fog on the interior of the windshield is sufficiently cleared.

20 The desirability of having automatic rain sensing is to have a system which automatically controls the windshield wipers during typical climatic conditions, such as rain, snow and fog. When the wiper system has to be operated manually during such typical conditions such a feature becomes undesirable.

25 **Summary Of The Invention**

It is an object of the present invention to provide a system which solves the problems of the prior art.

-4-

It is yet another object of the present invention to provide a system for automatically detecting the moisture content on the windshield of a vehicle.

5 It is yet another object of the present invention to provide a system for automatically detecting moisture on the windshield of a vehicle during common climatic conditions, such as rain, snow and fog.

It is yet a further object of the present invention to provide a system for automatically detecting the presence of fog on the exterior of a windshield.

It is yet another object of the present invention to provide a system for automatically detecting the presence of fog on the interior of a windshield.

10 It is yet a further object of the present invention to provide a system for automatically sensing the windshield wipers crossing a portion of the windshield.

Briefly the present invention relates to a system for automatically detecting moisture on the windshield of a vehicle. The automatic moisture detecting system includes an optical system for imaging a portion of the windshield onto an image array sensor, such as a CMOS active pixel sensor. The voltage of each of the pixels, which represents the illumination level, is converted to a corresponding gray scale value by an analog to digital converter. The gray scale values corresponding to the image are stored in memory. The spatial frequency 15 composition of the gray scale values are analyzed to determine the amount of rain present in order to provide a control signal to control the operation of the windshield wipers of the vehicle as a function of the amount of moisture present. The system is also adapted to detect fog both on the interior of the windshield as well as the exterior of the windshield. By providing a system for automatically 20 detecting the presence of fog on the interior and exterior of the windshield, serious performance limitations of known automatic rain sensors during typical climatic 25 conditions are eliminated.

-5-

Brief Description Of The Drawing

These and other objects of the present invention will be readily understood with reference to the following specification and attached drawing wherein:

5 FIG. 1 is a physical diagram which illustrates a vehicle windshield and an attached rearview mirror illustrating a system in accordance with the present invention.

FIG. 2 is an enlarged view of a portion of the system for sensing moisture on the exterior of a windshield in accordance with the present invention.

10 FIG. 3 is a physical diagram of a system in accordance with an alternate embodiment of the invention for sensing fog which illustrates the projection of a beam of light onto the windshield for fog detection.

15 FIGs. 4a and 4b are computer simulated spot diagrams which illustrate the performance of the optical system in accordance with the present invention during moisture and non-moisture conditions, respectively.

FIG. 5 is a flow diagram for the system in accordance with the present invention.

FIG. 6 is a block diagram of the system in accordance with the present invention.

20

Detailed Description Of The Invention

An automatic moisture sensing system in accordance with the present invention is able to detect moisture on the windshield of a vehicle in order to automatically control the vehicle's windshield wiper, defroster and/or defogging systems. The system for automatically sensing moisture on a vehicle windshield eliminates many of the performance deficiencies of known automatic moisture

-6-

sensing systems at a commercially viable cost. As used herein, the term moisture is used to designate various types of moisture and precipitation which can be found on the windshield of a vehicle during various climatic conditions, such as rainfall, snow fall, ice, fog as well as other substances that are commonly deposited on a 5 vehicle windshield such as bugs, dust and the like. The system is able to provide superior performance to other known systems during rather common climatic conditions, such as ice, fog and varying levels of rain and snow fall and the like.

As will be discussed in more detail below, a portion of the 10 windshield is imaged onto an image array sensor. An optical system which forms a portion of the present invention causes raindrops and other sources of moisture on the windshield to be sharply focused while distant objects beyond the windshield are severely blurred in the image. The processing system analyzes the image for sharp discontinuities caused by the edges of the water rain droplets or other moisture and by random focusing of the distant objects by the droplets. 15 These discontinuities represent high spatial frequency components. The magnitude of high spatial frequency components is a measure of the amount of the rain or other moisture on the vehicle which can be used to automatically control the vehicle windshield wipers. In an alternate embodiment of the invention the system is adapted to sense fog on the interior and exterior of the windshield in order to 20 prevent spurious operation of the automatic moisture sensing system. As such, the present invention eliminates many of the various performance limitations of known automatic moisture sensing systems.

In yet another alternate embodiment of the present invention, the 25 system is able to detect operation of the windshield wipers in order to prevent spurious operation and damage to the windshield wiper system during conditions when the windshield wipers are stuck or frozen to the windshield. As discussed above, the system analyzes the image of a portion of the windshield for sharp discontinuities which will have relatively high spatial frequency components. The magnitude of these high spatial frequency components is used to represent the

measure of moisture or other substances on the windshield. Thus, dust, bugs and other substances that will initially be treated as moisture. However, as discussed above, the system has the ability to automatically sense an operation of the windshield wiper blades. Thus, if the substance, which may be ice, dirt, cracks 5 or other substances not removable by the windshield wipers; remains on the windshield after one or more wipes, the system in accordance with the present invention may be configured to ignore such substances in order to prevent further spurious operation of the vehicle windshield wiper system.

Referring to FIG. 1, the automatic moisture sensing system in 10 accordance with the present invention generally identified with the reference numeral 20. The automatic moisture sensing system may be mounted stationary in the mounting bracket 22 of an automobile rearview mirror 24 or alternatively mounted in the rear portion of the rearview mirror housing 24. The automatic moisture sensing system 20 includes an image sensor mounted, for example, 2-3 15 inches behind the vehicle windshield 26 with the optical axis substantially parallel to ground or slightly angled to the ground. The angle of the windshield 26 in a modern passenger car is about 27°. Such a configuration may cause the raindrops and other moisture to be at a different distance from the image sensor depending on where the moisture is with respect to the field of view of the image sensor. To 20 help compensate for this problem, the image sensor may be angled approximately 10° toward the windshield 26 such that the top of the sensor 20 is moved closer to the windshield 26.

There are four main components to the automatic moisture sensing system 20: an imaging optical system; a light emitting diode; an image sensor; and 25 a processor. The imaging optical system is shown best in FIG. 2 while the image sensor is illustrated in FIG. 2 and in FIG. 6. A flow diagram for the microcontroller is illustrated in FIG. 5.

Imaging Optical System

The imaging optical system, generally identified with the reference numeral 30 (FIG. 2), is used to image a predetermined portion of the windshield 26 onto an image sensor 32 such that objects at the approximate distance of the windshield 26 are sharply in focus at the image plane while objects at a longer distance are out of focus and blurred. The area of the windshield 26 that is imaged must be large enough that the probability of receiving raindrops during relatively light rain conditions is significant. Moreover, the imaged area of the windshield must also be in the area of the windshield that is wiped by the windshield wipers.

10 The imaging optical system may include a single biconvex lens 33, used as an imaging lens. The lens 33 may have a diameter of 6mm; a front and rear radius of curvature of 7mm for each surface and a center thickness of 2.5mm. The front surface of lens 33 may be positioned 62mm from the outer surface of the windshield 26. The imaging lens 33 may be carried by a mechanical lens mount 34 which forms a stop 36 of about 5mm diameter directly in front of the lens 33. 15 The image sensor may be located about 8.55mm from the rear surface of the lens 33 and as mentioned above, slightly angled by about 10°.

More elaborate optical systems, for example, with multiple elements, aspherical elements, or refractive objects could all be used especially if 20 shorter distance from the windshield is a desired feature. However, since the collected images are not for photographic purposes, such optical quality is not necessary in an application for automatic moisture detection. A single lens may also be used molded in acrylic or other clear plastics at a relatively low cost. Various companies including Polaroid and Kodak specialize in high performance 25 molded plastic optics.

FIG. 4 illustrates a computer simulation of the performance of the imaging system illustrated in FIG. 2. In particular, FIG. 4a is a spot diagram of the imaging of approximately parallel light rays from a relatively distant object on the optical axis onto an image plane. FIG. 4b is a spot diagram of the imaging of

-9-

a point on the optical axis at the distance of the outer surface of the windshield. Upon comparison of the spot diagrams of FIGs. 4a and 4b, it is evident that the optical system is able to blur light coming from distant objects while focusing light from objects at the windshield distance.

5 Occasionally when driving up a hill, the vehicle could be positioned in such a way that the sun is directly imaged by the device. The radiative loading caused by this alignment may damage the image sensor 32 over time. In order to alleviate such a problem, an electrochromic filter may be used to temporarily eliminate most of the sunlight from the image plain. Other optical electronic or
10 optical mechanical devices could also be used.

Image Sensor

The image sensor 32 may be a CMOS active pixel sensor. CMOS active pixel sensors are a recent breakthrough in imaging technology that allow low cost, high sensitivity imaging on a chip manufactured in a CMOS process. Such
15 CMOS active pixel sensors have several advantages over other sensors including low power consumption, popular CMOS production techniques, low cost and ability to integrate additional circuitry on the same chip, variable read out windows and a variable light integration time. Such CMOS active pixel sensors are commercially available from Photobit LLC, La Cresenta, California. While
20 CMOS active pixel sensors have substantial advantages, other image sensors are also suitable and are considered to be within the scope of the present invention. The size and number of pixels is determined to image an area of the windshield sufficiently large and enough detail to adequately detect light rain while remaining cost effective. For example, a 64 x 64 active pixel, 40 μ m pixel size array will
25 image approximately a 25mm x 40mm area on a standard passenger car windshield.

-10-

Processing And Control

A block diagram of the automatic moisture sensing circuitry is shown in FIG. 6. As mentioned above, a predetermined portion of the windshield 26 is imaged onto an image array sensor 32. The analog voltage of each of the pixels within the sensor 32 is converted to digitized gray scale value by way of an analog to digital converter. The analog to digital converter 35 is operated under the control of a timing and control circuit 37 which, in turn, is controlled by a microcontroller 38. The timing and control circuit 37 is described in detail in U.S. patent application, Serial No. 933,210, entitled "Control Circuit For Image Array Sensors", by Jon Bechtel and Joseph Stam. A suitable microcontroller 38 is a Motorola type 68HC08XL36. However, it is commonly known that such microcontrollers do not contain sufficient random access memory (RAM) to store entire image from 50 x 50 pixel image sensor. In such a situation, a windowing feature of the CMOS imaging sensors may be used to alternatively image and process different regions of small enough size for the onboard RAM of the microcontroller 38.

As discussed above, the system analyzes the digitized gray scale values for sharp edges which are representative of rain drops or other moisture by analyzing the spatial high frequency components. The magnitude of the spatial high frequency components is used to control a windshield wiper motor control 40 such that the frequency of wiping of the windshield wiper blades (i.e. time interval between wipes) is controlled as a function of the amount of moisture on the windshield. As will be discussed in more detail below, the system also is able to detect the fog on the interior and exterior of the windshield. Thus, the microcontroller 38 may also be used to automatically control the vehicle defroster or defogging system 42. In order to provide selectivity of a system, a driver/on off sensitivity control circuit 44 may be provided. This control circuit 44 may be used in special circumstances for example when the vehicle is in an automatic car wash to prevent spurious operation of the system.

-11-

Once an image is acquired by the image array sensor 32, the luminance on each pixel, represented by an analog voltage, is converted to a digital gray scale value by the analog digital converter 35. These values are written to memory, which may be on board the microcontroller 38 and processed by the 5 microcontroller 38 or alternatively a digital signal processor.

Rain is detected by quantifying the discontinuity resulting from sharp edges of the raindrops on the windshield. These sharp edges are caused by the focused image of the rain or other moisture droplet along with the random optical imaging of far field objects by the droplets or other moisture. As discussed 10 in "Digital Image Processing" by R.C. Gonolez and R.E. Woods, Addison-Wesely 1992, the images may be analyzed in terms of their spatial frequency composition. Spatial frequency composition analysis is analogous to Fourier analysis, commonly used in both digital and analog signal processing. The process of taking a Fourier transform of a signal and determining its frequency composition can readily be 15 applied to two dimensional signals. When the two dimensional signal is an image, it is common to use the term spatial frequency. The spatial frequency composition of an image can be evaluated using a two dimensional Fourier transform of the image. The transform is given by equation (1) as follows:

(1)

$$F(\omega_x, \omega_y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) e^{-j\omega_x x} e^{-j\omega_y y} dx dy$$

20 where: $f(x, y)$ is the value of the pixel in the original image located at pixel x, y ; $F(\omega_x, \omega_y)$ is the value of the Fourier transform of the image at pixel location ω_x, ω_y ; j is the complex number $\sqrt{-1}$.

Equation (1) describes the Fourier transform for continuous infinite two dimensional signals. This function can be readily adapted to discrete, finite

-12-

two dimensional signals resulting from digital images. Applying spatial frequency analysis techniques, the rough edges or "roughness" of an image can be relatively accurately quantified. For example, a Fourier transform can be performed on a very blurry image. In such an analysis the value of $F(\omega_x, \omega_y)$ for low magnitudes ω of spatial frequencies ω_x, ω_y will be high while the value of $F(\omega_x, \omega_y)$ at high magnitudes of ω_x, ω_y will be low. The value of $F(\omega_x, \omega_y)$ where ω_x, ω_y are both 0 is always the average gray scale value of the image.

Alternatively, a Fourier analysis of a sharply focused image with many edges will result in the values of $F(\omega_x, \omega_y)$ for large magnitudes of ω_x, ω_y being high. A digital filter can be used to select particular spatial frequency regions. A relatively simple implementation of such a filter for image processing uses a 3×3 matrix supplied to a 3×3 pixel neighborhood as illustrated below:

A	B	C
D	E	F
G	H	I

A new image $g(x,y)$ can be formed which is the resultant image of applying the filter to the current image. The image may be processed in a looping fashion for every pixel with a value of $f(x,y)$ at a location defined by the variables x and y . In the above matrix, the location of the coefficient E corresponds to the current pixel at x and y . The pixel at location x and y in the new image has a value given by equation (2) below:

$$(2) \quad g(x,y) = A \cdot f(x-1, y-1) + B \cdot f(x, y-1) + C \cdot f(x+1, y-1) + D \cdot f(x-1, y) + E \cdot f(x, y) + F \cdot f(x+1, y) + G \cdot f(x-1, y+1) + H \cdot f(x, y+1) + I \cdot f(x+1, y+1)$$

A special filter commonly used is a Laplacian filter. The Laplacian is the second-order derivative of a two dimension function $f(x,y)$ given by equation 3:

-13-

(3)

$$\nabla^2 f = \frac{\partial^2 f}{\partial y^2} + \frac{\partial^2 f}{\partial x^2}$$

This Laplacian function can be implemented in discrete space using the 3 x 3 matrix described above with the coefficients as follows: E=4; B,D,F & H = -1 and the rest of the coefficients zero. Other coefficient combinations can also be
 5 used to compute variations of the discrete Laplacian as long as the coefficient E is positive and the rest are negative and that the sum of all coefficients is zero. The spatial frequency response of any 3 X 3 filter is determined by equation (4) below:

(4)

$$H(\omega_x, \omega_y) = \sum_{m=-1}^1 \sum_{n=-1}^1 h(m,n) e^{-j\omega_x m} e^{-j\omega_y n}$$

where:

10 $H(\omega_x, \omega_y)$ is the frequency response of the filter for frequencies ω_x and ω_y ; the function $h(m,n)$ describes the coefficients of the matrix above; the coefficient E is the value of $h(0,0)$, A is the value of $h(-1,-1)$, etc; j is the complex number $\sqrt{-1}$.

15 By analyzing the frequency response of the discrete 3 x 3 Laplacian filter using equation (4), it is evident that the discrete 3 x 3 Laplacian is a high pass filter. By modifying the coefficients, the particular response of the filter can be adjusted. Additionally, a 5 x 5 or larger filter can be used for even finer control over the response.

20 Rain drops and other moisture can be detected by using a 3 x 3 Laplacian filter described above. Every pixel is examined individually in a loop fashion and a variable used to store the total amount of "moisture" detected. The

-14-

Laplacian for each pixel is computed using the formula for $g(x,y)$ described above with the Laplacian coefficients.

A flow diagram in accordance with the present invention is illustrated in FIG. 5. Initially in step 46 an image of the windshield is acquired.

- 5 As mentioned above, the optical system in accordance with the present invention images the scene in such a way that distant objects are out of focus and objects at the windshield distance are in focus. Thus, if there is no moisture or other matter on the windshield, only a blurry image of distant objects will be captured. A blurry image will have a relatively low high frequency spatial component. Thus,
- 10 the value of the Laplacian in such a situation will be relatively low. If there is rain or other moisture on the windshield, the drops will be in focus and the image will contain relatively large high frequency components. Despite the blurring of distant objects by the optical system 30, oncoming head lamps from other vehicles which are relatively bright may contribute a significant high frequency spatial component.
- 15 In order to filter this component out, pixels which have a gray scale value above the saturation level of the analog to digital converter (i.e. pixels with a gray scale value at or near 255) may be skipped.

- In step 48, the Laplacian of each pixel is computed and the results are stored. More particularly, if the magnitude of a Laplacian is above a given
- 20 threshold, indicating a large enough high frequency spatial component to indicate rain or other moisture, this value is summed with the values of the other pixels to indicate the total value of rain or other moisture which is compared against a threshold, which may be a user set threshold as indicated in step 50. If the sum of the Laplacian of each of the pixels is greater than the threshold as determined
- 25 in step 52, windshield wipers are actuated in step 54. Otherwise the system loops back to step 46 and acquires a new image of the windshield.

The threshold indicated in step 52 may be a fixed threshold or a variable threshold. In applications where variable threshold is used, the threshold may be a user set threshold implemented by a control knob or slide with a voltage

-15-

output. This voltage output may then be sampled and converted to a digital value which is appropriately scaled for comparison with the sum of the pixels which indicate the total amount of rain.

In order to prevent spurious operation of the system, the operation
5 of the wiper blade is sensed in step 56. In particular, a small sub window of the
image array sensor may be selected to allow more cycles to be processed per
second in order to detect a relatively rapidly moving windshield wiper. An image
of the wiper is acquired in step 56. Each image is processed using two one
10 dimensional high pass filters; one for the vertical direction and one for the
horizontal direction as indicated in step 58. Since the windshield wiper will appear
as a vertical line in an image, there should be a significantly higher high frequency
component in a horizontal direction than in a vertical direction. Thus, a vertical
high pass filter may be implemented using a 3 x 3 matrix described above with the
coefficient E set to 2, coefficients B and H set to -1 and the rest set to zero. A
15 horizontal filter is implemented with the coefficient E set to 2, the coefficients D
and F set to -1 and the rest set to zero. The sum of each component is tallied in
the same fashion as used to compute the Laplacian discussed above. In step 60,
the ratio of the horizontal component to the vertical component is computed. If the
horizontal component is much greater than the vertical component, a vertical line
20 is assumed to be present in the image indicating the presence of the windshield
wipers.

If the wipers of the automobile are designed in such a way that the
wipers are never approximately vertical when it crosses the rain sensing area, the
filters described above can be modified to accommodate such a configuration. For
25 example, various other edge detection methods well known in the art of image
processing can also be used. Additionally, if the wiper speed for the vehicle
windshield wipers is so fast that it blurs slightly in the image for the necessary
exposure time, the horizontal filter can be modified to subtract the pixels two

-16-

positions to the left and right of the current pixel instead of the pixels immediately next to the current pixel.

After the wiper has cleared the image sensing area, as indicated in step 62, another image of the windshield is acquired in step 64 for which the 5 Laplacian is computed. This computation is used as a zero point measurement that may be subtracted from all subsequent measurements until the next wipe. In this way, long term high frequency spatial components in the image of dirty windshield, cracks, scratches and frozen ice will not contribute to the detected amount of rain.

10 If the windshield wiper is not detected within a given time frame, the system assumes that a malfunction has occurred, which can be caused as a result of the windshield wiper being frozen to the windshield. During such a condition, the operation of the moisture sensor in accordance with the present invention can be suspended for a period of time to allow the ice to thaw. If outside 15 temperature information is available, freezing climate conditions can be taken into account to decide if the wipers are failing because of a mechanical malfunction or due to ice.

The system is also able to adapt to varying light levels. In particular, during selected cycles, the average gray scale value of the image may 20 be computed. If this value is high, indicating an over exposure to light, the image sensor integration time in the following cycle may be reduced to lower the average brightness. Similarly, if the light level is low, the integration time may be increased. In relatively dark conditions, some image sensors may not be capable 25 of collecting enough light in a reasonable time to adequately image moisture such as raindrops. In such a situation, an additional illuminator may be provided to briefly illuminate the area of interest from behind while the image is being taken. If the windshield of the vehicle is not highly absorbent to infrared radiation, a near infrared illuminator can be used as long as the wavelengths are within the

-17-

detectable region of the image sensor. An infrared illuminator has the benefit of not being visible to the human eye and thus not distracting to the driver.

Fog Detector

In order to eliminate many of the operational deficiencies of known moisture sensing systems, the system in accordance with an alternate embodiment of the invention includes a system for detecting fog on the interior and the exterior of the windshield. As illustrated in FIGs. 2 and 3, a light emitting diode (LED) may be used for detecting fog both on the interior and the exterior of a vehicle windshield 26. Two different embodiments of the fog detection systems are disclosed both of which rely on the difference in the way the light from the LED 66 is reflected from the windshield 26 in the presence of fog. Fog detection may be done in alternate processing cycles with the rain detection. In particular, many cycles may be used for rain and moisture detection between fog detection cycles due to the slow onset of windshield fogging. At the beginning of the fog detection cycles, an image may be acquired using a window containing the expected location of the spots.

In a first embodiment, a light source that is either highly collimated or focused to a point at the windshield distance can be used. The light source can be either infrared emitting or visible emitting depending upon the absorption characteristics of the windshield. Infrared sources are preferable since they are not visible to the human eye and therefore do not pose a distraction. An infrared LED 66 may be used along with a lens 68 of a focal length equal to the windshield distance as generally shown in FIG. 2. The LED 66 may be positioned a few millimeters above the main optical assembly and angled so that the projected light as shown in FIG. 3 is aimed at the position of the main optical axis on the windshield 26. The LED 66 is initially turned off and an image is taken. Immediately following, the LED is turned on and a second image is taken. The difference between these images is used for spot detection. If no fog is present,

-18-

the light will reflect from the windshield 26 at the Snell angle which will carry it well outside the field of view of the image sensor 32. If fog is present, the light will be reflected by Lambertian reflectance causing the fog to be imaged as a small spot 70 (FIG. 3). Due to the angles of the windshield 26 and the light source 66, 5 outside fog will produce a spot 70 lower than a spot 72 produced by fog in the interior surface of the windshield 26. The location of these spots 70, 72 may be used to represent the presence of interior and/or exterior fog on the windshield 26. If fog is present on the interior of the windshield, exterior fog detection is not possible. However, this limitation is of no consequence because vision would be 10 impaired anyway. The following truth table indicates the conclusions drawn from the presence of each spot:

	Exterior (Lower) Reflected Spot	Interior (Upper) Reflected Spot	Result
15	Present	-----	Exterior Fog
	-----	Present	Interior Fog
	Not Present	Not Present	No Fog

In an alternate embodiment an infrared or, if necessary, a visible LED is used. The LED must be either relatively small or be used in conjunction with a pin hole and aimed such that the light from the LED reflects off the 20 windshield 26 and on to an image sensor at the Snell angle. In such a configuration, two reflections will occur: one off the inside of the windshield and one from the outer surface of the windshield by specular reflection. In this embodiment if fog is not present, the spots are reflected at the Snell angle and are visible by the image sensor. If there is fog on the exterior surface of the 25 windshield 26, the spot from the interior reflection will be present but the spot from the exterior refection will be a blur. The difference image is analyzed for interior fog. Initially a 3 x 3 Laplacian filter is used to create a new image which

-19-

contains only the high frequency components of the original image. In this way the blurred reflection from fog is illuminated. The spots are detected by taking the maximum value of a group of pixels in the expected region of each spot. A group slightly larger than the expected size of the spot may be used in order to correct
5 for slight misalignments and for the fact that the Laplacian will only preserve the edges of the spots where the high frequency components are present. Also slight fog may cause the spot to grow but may not require action. For each spot, if the value is reasonably greater than zero, it is determined to be present. The following truth table indicates the detection of fog for the alternate embodiment.

10	Exterior (Upper) Reflected Spot	Interior (Lower) Reflected Spot	Result
	Present	Present	No Fog
	Not Present	Present	Exterior Fog
	Not Present	Not Present	Interior Fog

15 If the exterior fog is detected, the windshield wipers may be actuated to help remove the fog or if desired a warning light can be used to indicate this condition to the driver. Interior fog detection can be used to automatically actuate the vehicle defrost or defogger system preventing the driver from waiting until the significant fog has developed. More involved processing methods may
20 include determining the size of the spot by computing the distance between the horizontal edges of the spot and thus having a measurement of the quantity of fog on the windshield which can be compared to a threshold.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings. Thus, it is to be understood
25 that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described above.

-20-

What Is Claimed Is:

1. A system for detecting moisture on a surface comprising:
an image sensor;
an optical system operable to image a portion of the surface onto the
5 image sensor, to focus objects at the surface onto the image sensor, and to blur
objects away from the surface; and
a processor in communication with the image sensor, the processor
operative to determine spatial composition of the image whereby a signal may be
generated based on the determined spatial composition.

- 10 2. The system for detecting moisture on a surface as in claim 1, the
surface comprising a vehicle window.

- 15 3. The system for detecting moisture on a surface as in claim 1, the
system further comprising an electrochromic window disposed between the surface
and the imaging optical system, the electrochromic window operative to reduce the
amount of light imaged by the image sensor.

- 20 4. The system for detecting moisture on a surface as in claim 1, the
image sensor comprising a CMOS active pixel sensor.

- 25 5. The system for detecting moisture on a surface as in claim 1, the
image sensor comprised of a plurality of pixel sensors, each pixel sensor operative
to produce an analog signal indicative of a pixel illumination level, the system
further comprising an analog-to-digital converter for determining a gray scale
value from the illumination level.

6. The system for detecting moisture on a surface as in claim 5, the
image sensor having a variable integration time, the system operable to control the
variable integration time of the image sensor.

-21-

7. The system for detecting moisture on a surface as in claim 5, the processor operable to determine image spatial composition by high pass digital filtering of a set of gray scale values.

5 8. The system for detecting moisture on a surface as in claim 7, wherein high pass digital filtering is accomplished using a Laplacian filter.

9. The system for detecting moisture on a surface as in claim 1, the system further including an illuminator to illuminate the imaged portion of the window.

10 10. The system for detecting moisture on a surface as in claim 1, the vehicle having a wiper for wiping the surface along a path, the wiper driven by a wiper motor, the system further comprising a wiper motor control in communication with the processor and the wiper motor, wherein the generated signal is based on the determined spatial composition used to control the wiper.

15 11. The system for detecting moisture on a surface as in claim 10 wherein the imaged portion of the surface includes the path of the wiper and the processor is further operable to determine if the wiper is in the imaged portion of the surface using the determined spatial composition.

20 12. The system for detecting moisture on a surface as in claim 11 wherein the processor is further operative to (a) acquire an image of the surface after the wiper has cleared the imaged portion of the surface; and (b) to determine a zero point using the image acquired after the wiper has cleared the imaged portion of the surface.

25 13. The system for detecting moisture on a surface as in claim 11 wherein the processor is further operative to suspend operation of the wiper if the wiper has not been detected within a time frame.

-22-

14. The system for detecting moisture on a surface as in claim 10,
the system further comprising a driver on/off sensitivity control in communication
with the processor.

15. The system for detecting moisture on a surface as in claim 1,
5 the system further comprising a light source in communication with the processor
for projecting a light spot at the imaged portion of the surface in communication
with the processor, the processor further operable to
turn on the light source,
obtain a first image of the surface with the light source on,
10 turn off the light source,
obtain a second image of the surface with the light source off, and
determine if moisture is present on the surface using the first image
and the second image.

16. The system for detecting moisture on a surface as in claim 15
15 wherein the moisture comprises fog or frost.

17. The system for detecting moisture on a surface as in claim 15
wherein the light source is positioned such that, when moisture is present on the
surface, the light spot is reflected into the image sensor field of view.

18. The system for detecting moisture on a surface as in claim 15
20 wherein the light source is positioned such that, when moisture is not present on
the surface, the light spot is reflected into the image sensor field of view.

19. The system for detecting moisture on a surface as in claim 15
wherein the surface comprises a window, the window having an interior side and
an exterior side, the light source positioned such that the light spot reflected into
25 the image sensor field of view from the interior side is located at a different
position on the image sensor than the light spot reflected from the exterior side,

-23-

the processor further operative to determine the location of moisture on either the interior side or the exterior side from the position of the reflected light spot in the image sensor output.

20. The system for detecting moisture on a surface as in claim 15
5 wherein the processor is further operative to create a filtered image containing high frequency components of the image sensor output.

21. The system for detecting moisture on a surface as in claim 15
wherein the light source comprises a visible light emitting diode.

22. The system for detecting moisture on a surface as in claim 15
10 wherein the light source comprises an infrared light emitting diode.

23. The system for detecting moisture on a surface as in claim 15,
the vehicle having a means for clearing frost or fog from the surface, the system
further comprising a control in communication with the processor and the clearing
means, the processor further operative to control moisture clearing based on the
15 determined presence of moisture on the surface.

24. A system for detecting moisture on a window, the window
having an interior surface and an exterior surface, the system comprising:
a light source projecting a light spot onto the window;
an image sensor;
20 an imaging optical system operable to image a portion of the
window including the projected light spot onto the image sensor, to focus objects
on the window onto the image sensor, and to blur objects away from the window,
wherein
the light source is positioned such that the light spot reflected into
25 the image sensor field of view from the interior surface is located at a different

-24-

position on the image sensor than the light spot reflected from the exterior surface;
and

5 a processor in communication with the image sensor and the light source, the processor operative to determine the presence of moisture and to determine the location of moisture on either the interior surface or the exterior surface, whereby a signal may be generated based on the determined presence of moisture and the determined location of moisture.

10 25. The system for detecting moisture on a window as in claim 24, the light source positioned relative to the window and the imaging optical system such that, when moisture is present on at least one of the interior surface and the exterior surface, the light spot is reflected from the window, through the imaging optical system, and onto the image sensor.

15 26. The system for detecting moisture on a window as in claim 24, the light source positioned relative to the window and the imaging optical system such that, when moisture is present on at least one of the interior surface and the exterior surface, the light spot is not reflected onto the image sensor.

20 27. The system for detecting moisture on a window as in claim 24 wherein the light source comprises a visible light emitting diode.

25 28. The system for detecting moisture on a window as in claim 24 wherein the light source comprises an infrared light emitting diode.

25 29. The system for detecting moisture on a window as in claim 24, the vehicle having a means for clearing fog or frost from the window, the system further comprising a control in communication with the processor and the clearing means, the processor further operative to control the clearing means based on the determined presence of moisture on the window.

-25-

30. The system for detecting moisture on a window as in claim 24, the processor further operable to extract high spatial frequency components of the image sensor output.

31. A method for detecting moisture on a surface comprising:
5 acquiring an image of a portion of the surface, the image having objects on the surface in focus and objects away from the surface blurred;
 generating a signal corresponding to the acquired image;
 determining spatial high frequency components of the signal; and
 determining the moisture using the spatial high frequency
10 components.

32. The method for detecting moisture on a surface as in claim 31 wherein generating the signal comprises digitizing the acquired image.

33. The method for detecting moisture on a surface as in claim 31 further comprising:
15 determining if a radiative loading greater than a threshold is imaged;
 and
 temporarily reducing the radiative loading greater than the threshold from the image.

34. The method for detecting moisture on a surface as in claim 31
20 further comprising:
 determining the amount of light integrated by an image sensor having a variable light integration time; and
 controlling the variable integration time of the image sensor based on the determined amount of integrated light.

-26-

35. The method for detecting moisture on a surface as in claim 31 wherein determining spatial high frequency components of the digitized signal comprises high pass digital filtering of the digitized signal.

36. The method for determining moisture on a surface as in claim
5 31 wherein the high pass digital filtering is accomplished using Laplacian filtering.

37. The method for detecting moisture on a surface as in claim 31 further comprising illuminating the imaged portion of the surface.

38. The method for detecting moisture on a surface as in claim 31,
10 the vehicle including a wiper for wiping the surface along a path, the imaged portion of the surface including the path of the wiper wherein the method further comprises detecting the presence of the wiper in the imaged portion of the surface.

39. The method for detecting moisture on a surface as in claim 38 wherein detecting the presence of the wiper comprises determining if a plurality of high frequency components in the direction of wiper travel through the imaged
15 portion of the surface are greater than a plurality of high frequency components in a direction normal to the direction of wiper travel through the imaged portion of the surface.

40. The method for detecting moisture on a surface as in claim 39 further comprising controlling the rate of the wiper based on the determined signal
20 representative of moisture.

41. The method for detecting moisture on a surface as in claim 40 further comprising preventing further operation of the wiper if the wiper has not been detected within a time frame.

-27-

42. A method for detecting moisture on a surface, the vehicle having at least one wiper for wiping the surface, the vehicle including an image sensor operable to image the surface in a region covered by the at least one wiper, the method comprising:

- 5 acquiring an image of the surface, the image having objects at the surface in focus and objects away from the surface blurred;
- determining a sum, the sum comprising a Laplacian for each pixel;
- determining a difference of a zero calibration subtracted from the sum;
- 10 repeating the steps of acquiring the image, determining the sum, and determining the difference if the difference is less than a threshold, otherwise actuating at least one wiper;
- determining that the at least one actuated wiper has wiped the imaged region of the surface; and
- 15 determining as the zero calibration the Laplacian of an image taken after the imaged region of the surface has been wiped.

43. The method for detecting moisture on a surface as in claim 42 wherein determining that the at least one wiper has wiped the imaged region of the surface comprises:

- 20 acquiring an image of the surface, the image having objects at the surface in focus and objects away from the surface blurred;
- determining a first filtered image by passing the image of the surface through a first one-dimensional high pass filter, the one dimension in the direction of wiper travel through the image of the surface;
- 25 determining a second filtered image by passing the image of the surface through a second one-dimensional high pass filter, the one dimension in the direction normal to the direction of wiper travel through the image of the surface;

-28-

repeating the steps of acquiring an image of the surface, determining a first filtered image, and determining a second filtered image if a first sum of values of the first filtered image is not greater than a second sum of values of the second filtered image, otherwise

- 5 delaying for a time to allow the wiper to pass out of the image of the surface.

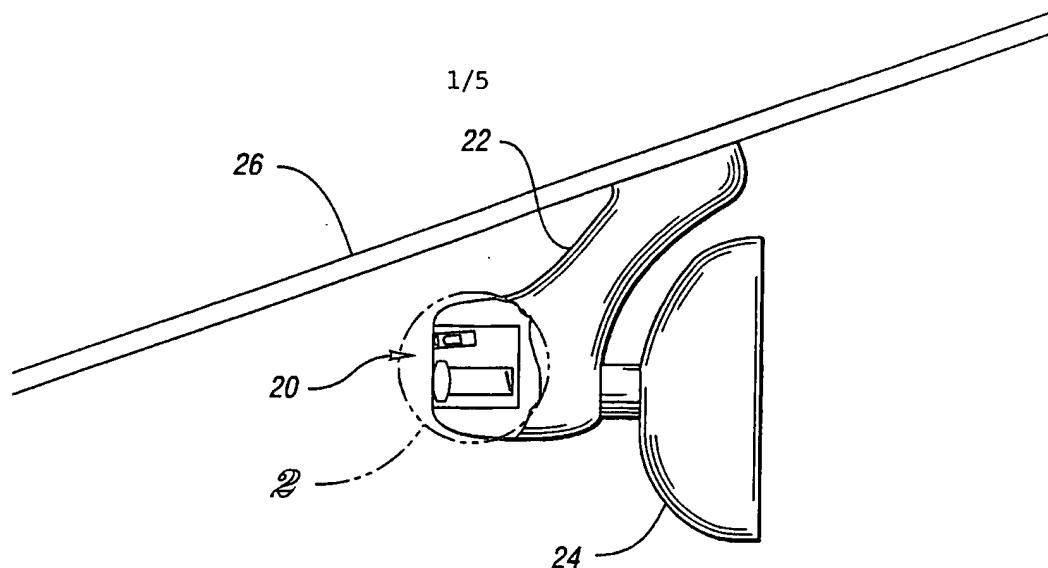


Fig. 1

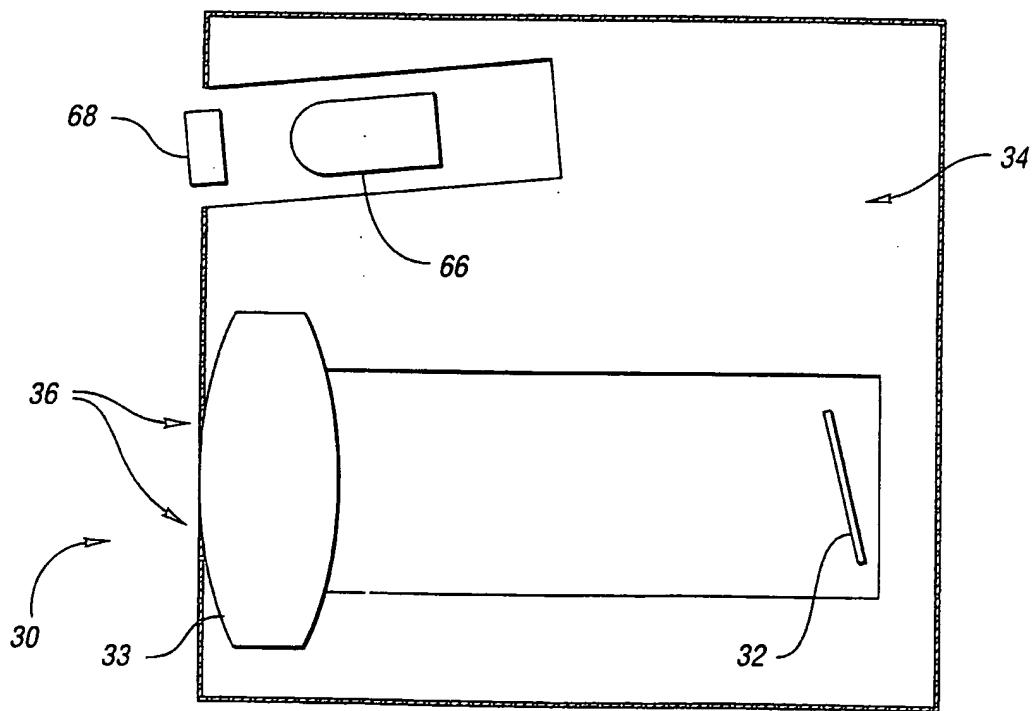


Fig. 2

2/5

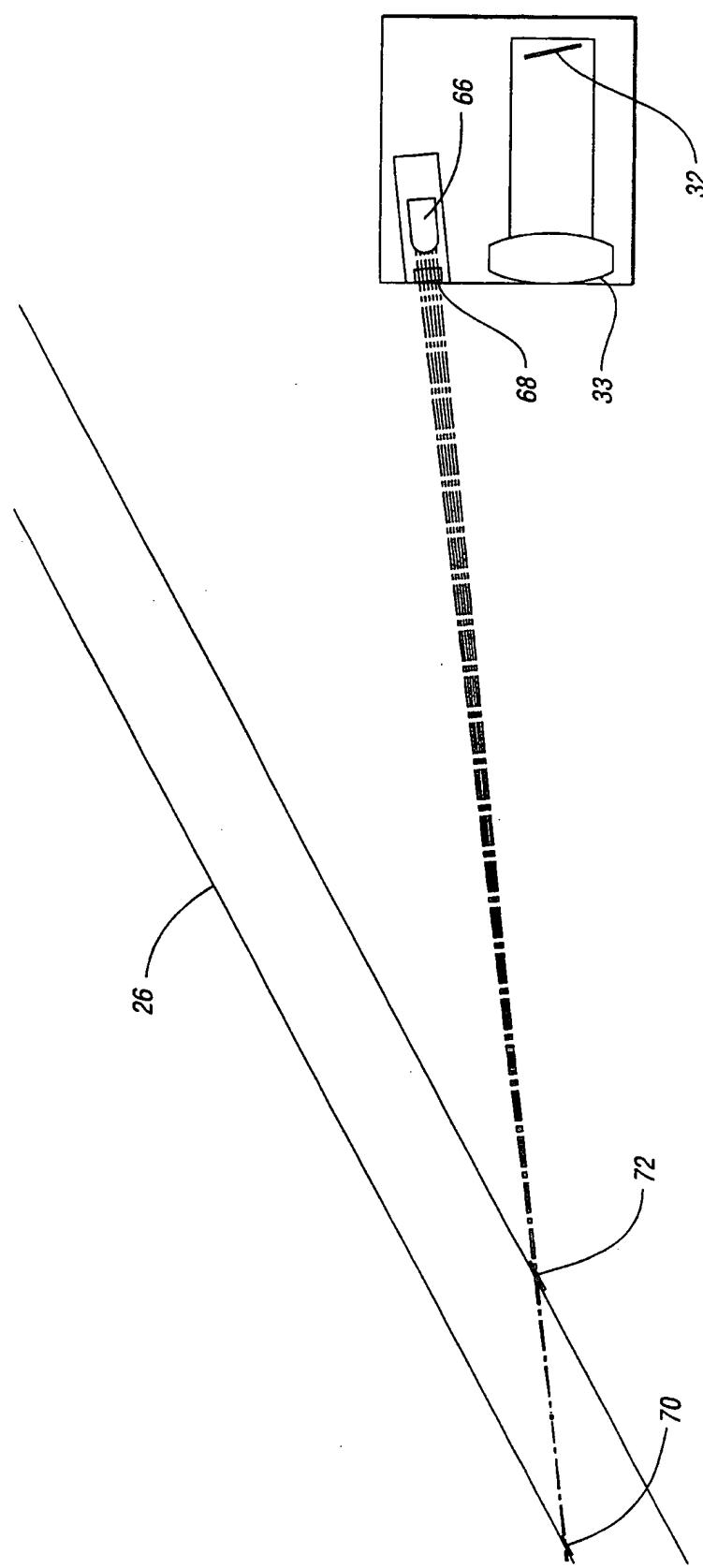


Fig. 3

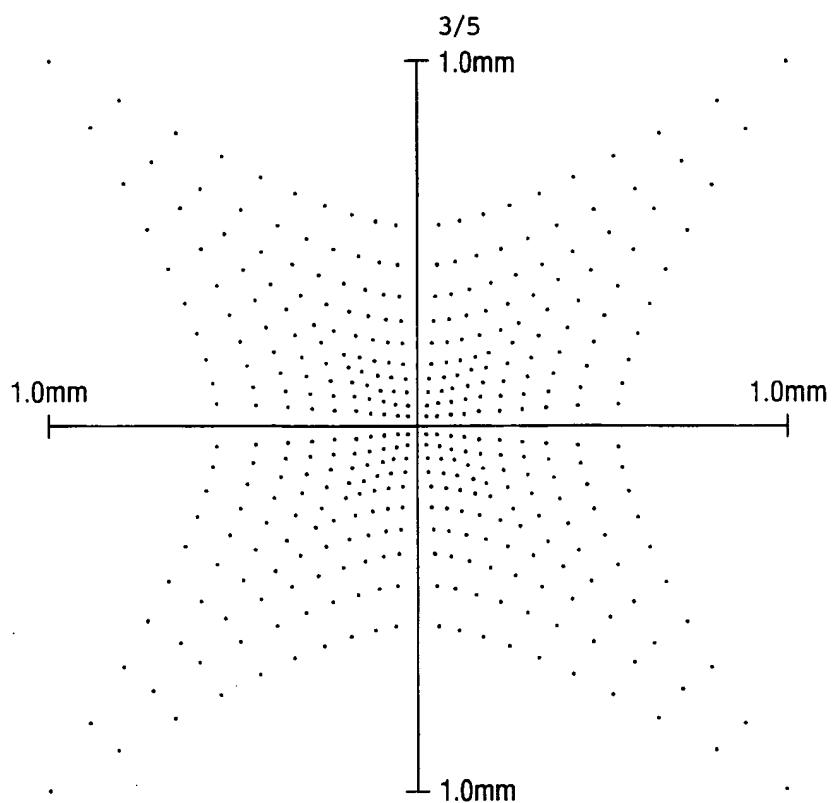


Fig. 4a

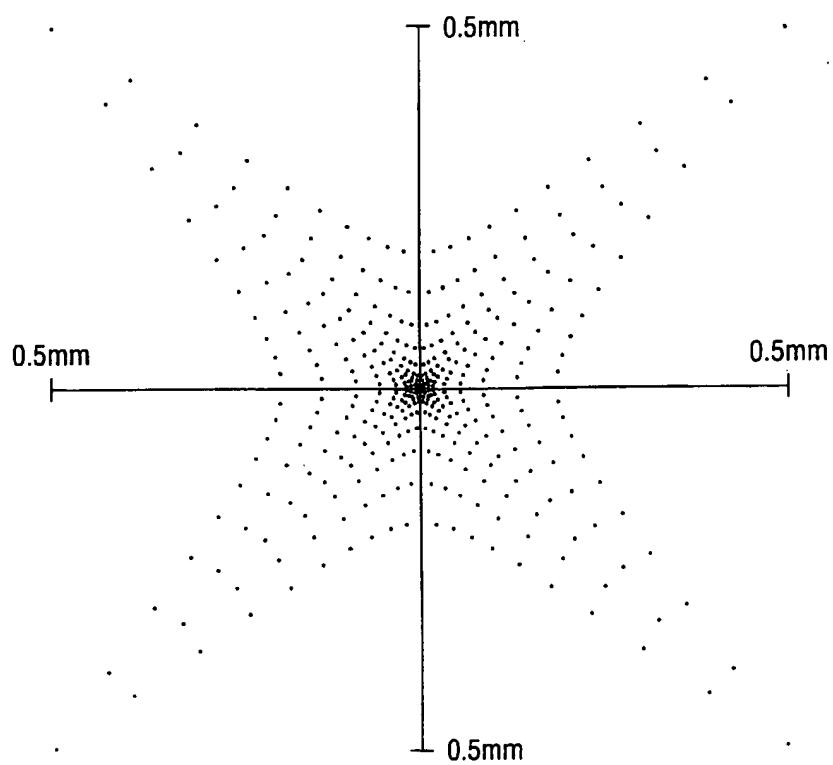
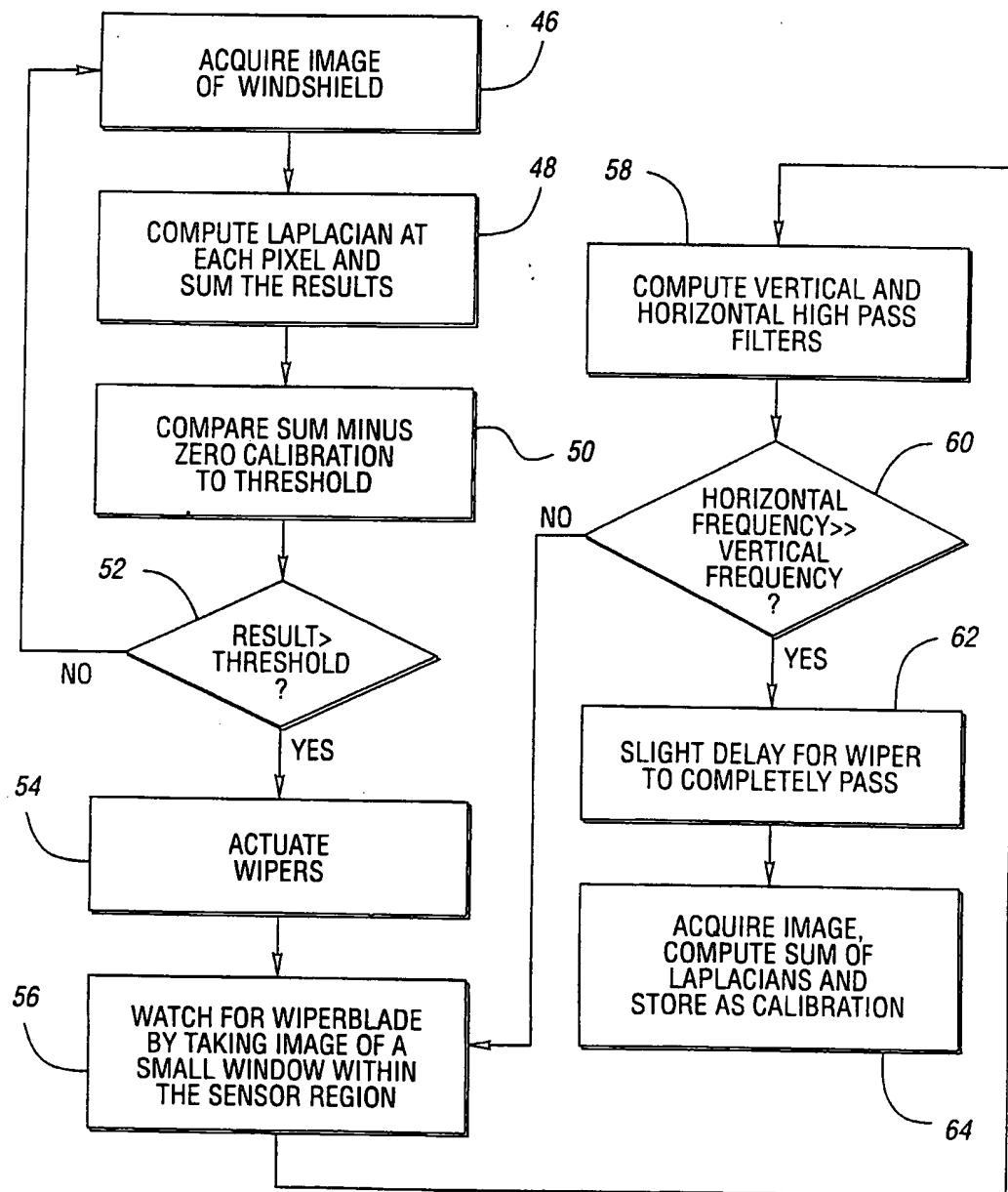
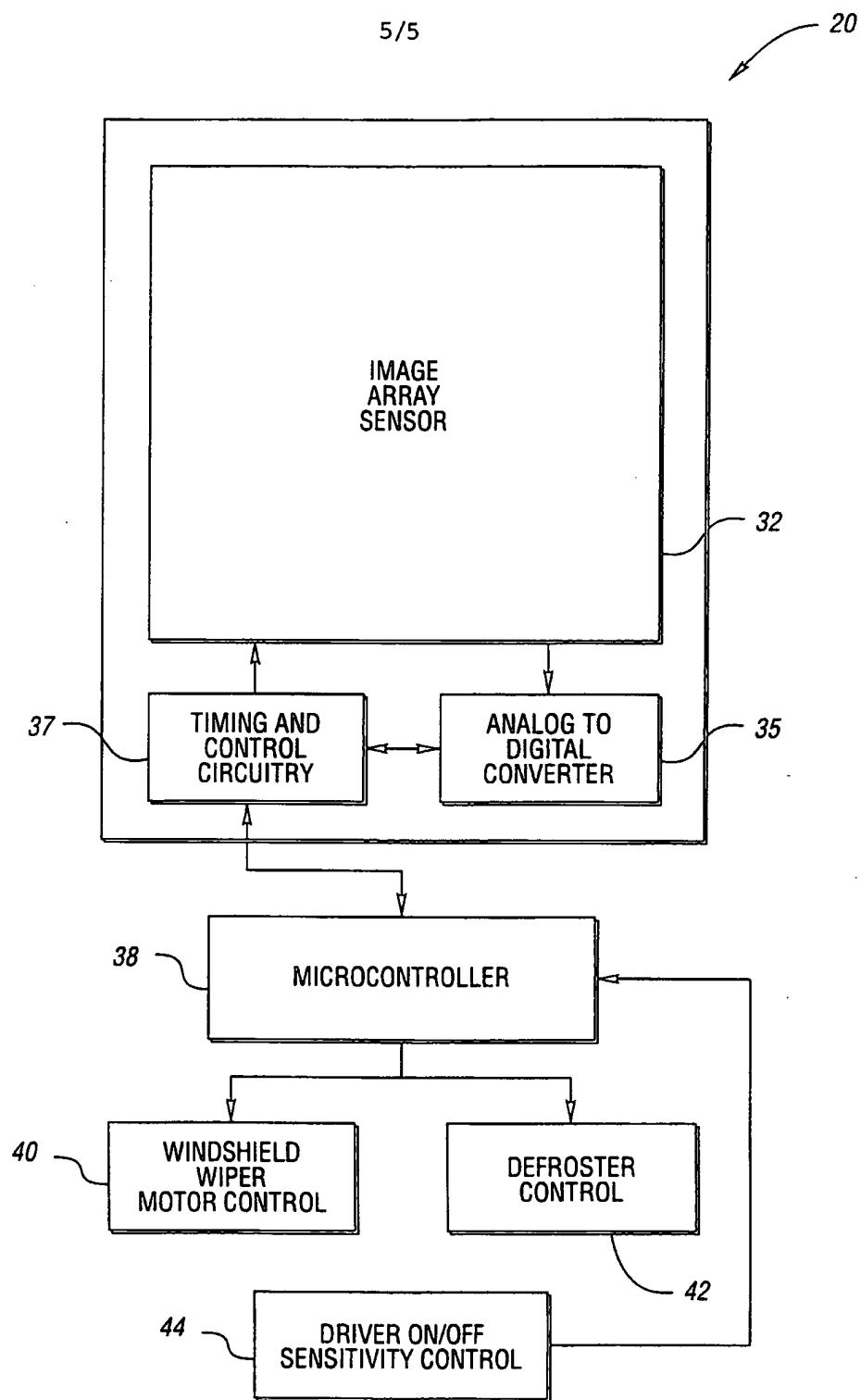


Fig. 4b

4/5

*Fig. 5*

5/5

*Fig. 6*

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 98/18899

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
US 4867561	A	19-09-1989		JP 1025036 A JP 63053444 A		27-01-1989 07-03-1988
US 5276389	A	04-01-1994		DE 4141348 A US 5336980 A DE 4217391 A DE 59205686 D EP 0547337 A US RE35422 E US 5276388 A US 5319293 A		17-06-1993 09-08-1994 02-12-1993 18-04-1996 23-06-1993 14-01-1997 04-01-1994 07-06-1994
DE 4424454	A	18-01-1996		BR 9502340 A DE 59504131 D EP 0705745 A US 5818600 A		18-06-1996 10-12-1998 10-04-1996 06-10-1998
EP 0479169	A	08-04-1992		JP 4138390 A US 5160971 A		12-05-1992 03-11-1992
GB 2056059	A	11-03-1981		DE 2932461 A BE 884706 A FR 2466767 A		26-02-1981 01-12-1980 10-04-1981
US 5386111	A	31-01-1995		CA 2132393 A DE 69408250 D EP 0647551 A JP 7181131 A US RE35762 E		09-04-1995 05-03-1998 12-04-1995 21-07-1995 07-04-1998

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/18899

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B60S1/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 B60S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 867 561 A (FUJII ET AL) 19 September 1989 see column 3, line 62 - column 6, line 24 ---	1,2,4,9, 10,15, 16,18, 19, 22-24, 26,28,29
X	US 5 276 389 A (LEVERS) 4 January 1994 see column 9, line 60 - column 11, line 40 ---	1,2,10
A	DE 44 24 454 A (LOPOLD KOSTAL) 18 January 1996 see column 2, line 58 - column 3, line 13 ---	1
A	EP 0 479 169 A (ISUZU MOTORS) 8 April 1992 see column 5, line 7 - line 49 ---	11-13
		-/-

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- "&" document member of the same patent family

Date of the actual completion of the international search

7 January 1999

Date of mailing of the international search report

15/01/1999

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl.
Fax: (+31-70) 340-3016

Authorized officer

Standring, M

INTERNATIONAL SEARCH REPORT

Int'l Application No
PCT/US 98/18899

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 056 059 A (ROBERT BOSCH) 11 March 1981 see page 2, line 44 - line 64 ---	1
A	US 5 386 111 A (ZIMMERMAN) 31 January 1995 see column 6, line 10 - line 31 ---	1
A	PATENT ABSTRACTS OF JAPAN vol. 9, no. 67 (M-366) '1790!', 27 March 1985 & JP 59 199347 A (NIPPON DENSO) see abstract -----	1